TA
1
I35
v.117

UC-NRLF
B 2 869 408

YD 00278

UNIVERSITY OF ILLINOIS BULLETIN
ISSUED WEEKLY
Vol. 17 January 26, 1920 No. 22
Entered as second-class matter December 11, 1912, at the post office at Urbana, Illinois, under the Act of August 24, 1912. Acceptance for mailing at the special rate of postage provided for in section 1103, Act of Oct. 3, 1917, authorized July 31, 1918.]

EMISSIVITY OF HEAT FROM VARIOUS SURFACES

BY

V. S. DAY

LIBRARY
JUN 19 1957
UNIVERSITY OF CALIFORNIA

P
P.D.
117
TH
7
135
ENGIN.
LIBRARY

[THIS BULLETIN IS THE SECOND OF A SERIES ON WARM-AIR FURNACE RESEARCH]

BULLETIN No. 117

ENGINEERING EXPERIMENT STATION
PUBLISHED BY THE UNIVERSITY OF ILLINOIS, URBANA

PRICE: TWENTY CENTS

EUROPEAN AGENT
CHAPMAN & HALL, LTD., LONDON

THE Engineering Experiment Station was established by act of the Board of Trustees, December 8, 1903. It is the purpose of the Station to carry on investigations along various lines of engineering and to study problems of importance to professional engineers and to the manufacturing, railway, mining, constructional, and industrial interests of the State.

The control of the Engineering Experiment Station is vested in the heads of the several departments of the College of Engineering. These constitute the Station Staff and, with the Director, determine the character of the investigations to be undertaken. The work is carried on under the supervision of the Staff, sometimes by research fellows as graduate work, sometimes by members of the instructional staff of the College of Engineering, but more frequently by investigators belonging to the Station corps.

The results of these investigations are published in the form of bulletins, which record mostly the experiments of the Station's own staff of investigators. There will also be issued from time to time, in the form of circulars, compilations giving the results of the experiments of engineers, industrial works, technical institutions, and governmental testing departments.

The volume and number at the top of the front cover page are merely arbitrary numbers and refer to the general publications of the University of Illinois: *either above the title or below the seal is given the number of the Engineering Experiment Station bulletin or circular which should be used in referring to these publications.*

For copies of bulletins, circulars, or other information address the

ENGINEERING EXPERIMENT STATION,
URBANA, ILLINOIS.

UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

BULLETIN NO. 117 JANUARY, 1920

EMISSIVITY OF HEAT FROM VARIOUS SURFACES
WITH SPECIAL REFERENCE TO
WARM-AIR FURNACE INSTALLATIONS

RESULTS OF COMPARATIVE TESTS ON
COVERED AND UNCOVERED SHEET METAL SURFACES
MADE IN CONNECTION WITH THE
WARM-AIR FURNACE INVESTIGATION

CONDUCTED BY
THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
IN COÖPERATION WITH
THE
NATIONAL WARM-AIR HEATING AND VENTILATING
ASSOCIATION

BY
V. S. DAY
RESEARCH ASSISTANT, ENGINEERING EXPERIMENT STATION

ENGINEERING EXPERIMENT STATION
PUBLISHED BY THE UNIVERSITY OF ILLINOIS, URBANA

Replacement

TA1
I35 ENGI
LIBRA
v.117

CONTENTS

PAGE

I. INTRODUCTION 5
  1. Preliminary Statement 5
  2. Previous Investigations 5
  3. Acknowledgments 6
  4. Significant Conclusions 6

II. THE TESTING EQUIPMENT 7
  5. Description 7

III. THE TESTS 12
  6. Operation 12
  7. Specimens Tested 13

IV. THE CALCULATIONS 14

V. THE RESULTS 16
  8. Discussion 16

VI. CORROBORATIVE TESTS 26
  9. The Auxiliary Air Plant 26
  10. Temperature Measurement 27
  11. Calculation 30
  12. Conclusion 31

LIST OF FIGURES

NO. PAGE

1. Sectional Elevation of Steam Drum Plant for Testing Surfaces for Heat Emissivity 8

2. Photograph Showing the Principal Operative Features of the Steam Drum Plant 9

3. A Sample Data Sheet for a Typical Test 15

4. Sections Showing Construction of Some of the Complex Surface Coverings 16

5. Diagrammatic Table of the Results of One Hundred Sixty Tests on Steam Drums 18, 19

5*a*. Continuation of the Diagrammatic Table of the Results of One Hundred Sixty Tests on Steam Drums . . . 20, 21

6. Elevation of Auxiliary Furnace Plant with Insert Showing Percentage of Heat Lost from Covered and from Bare Bright Tin Pipes 22

7. Curves Showing Ineffectiveness of Commercial Asbestos Paper for Insulation of Bright Tin Pipes 23

8. Diagram of Thermocouple Connections to the Auxiliary Testing Plant 26

9. Temperature Traverse Curves of Ten-Inch Leader Pipe . . 27

10. Data for a Temperature Traverse Test on the Auxiliary Furnace Testing Plant 29

EMISSIVITY OF HEAT FROM VARIOUS SURFACES

I. INTRODUCTION

1. *Preliminary Statement.*—The work reported upon in this bulletin was done in connection with the Warm-Air Furnace Investigation now in progress at the University of Illinois. This investigation has for its object the determination of the efficiencies and capacities of warm-air furnaces and a study of the proper conditions of installation and operation, so that furnaces may be accurately rated and properly selected for the requirements of actual service. The work is being conducted under a coöperative agreement between the National Warm-Air Heating and Ventilating Association and the Engineering Experiment Station of the University of Illinois. This bulletin is a report of the tests of heat insulating materials and surfaces made as a part of the Investigation, and is included in item (4) of the Objects of the Investigation.*

2. *Previous Investigations.*—In May 1919, it was observed in these tests that greater temperature reduction occurred in air passing through bright tin pipes covered with asbestos paper, such as are commonly used in furnace heating, than occurred in air passing through the same bright tin pipes uncovered, all other conditions in the comparative tests being the same. It was therefore evident that the actual heat loss was greater through the asbestos paper-covered pipes than through the same pipes uncovered.

This fact was reported at the annual Spring Meeting of the National Warm-Air Heating and Ventilating Association, Columbus, Ohio, June 11, 1919, as follows: " . . We found that we lost about 35 per cent more heat through the pipe covered with asbestos paper than through the same tin pipe not covered. . . This great loss amounts to approximately 5 per cent of the coal consumed. . . Furthermore, it costs from ten to fifteen dollars to cover the heat pipes of the average house installation with asbestos paper."†

---

* University of Illinois Engineering Experiment Station, Bulletin No. 112, "A Report of Progress in Warm-Air Furnace Research," by Prof. A. C. Willard, p. 8.

† Proceedings of the National Warm-Air Heating and Ventilating Association, p. 70. June 11, 1919.

Because of the inefficacy of many of the present warm-air furnace heat insulating methods, it is evident that a complete study of various insulating materials, coverings, and surfaces would be justified.

3. *Acknowledgments.*—Credit is due Professor A. C. WILLARD for the original idea of the scheme for testing the samples, and for the keen support which, as the active supervisor of the Investigation, he gave this work.

Professor A. P. KRATZ gave valuable advice and assistance in the use of the thermocouples.

4. *Significant Conclusions.*—The results of the tests have been given some publicity heretofore, but not in the complete form presented in this bulletin. The following significant results as applied to warm-air furnace heating are deserving of special emphasis.

(1) The use of thin sheets of asbestos paper on bright tin heat pipes results in a waste of heat. The use should be abandoned.

(2) Uncovered bright tin pipes are more efficient carriers of heated air than asbestos paper-covered bright tin pipes. See item (4).

(3) This fact is true regardless of the degree of brightness of the tin surface.

(4) No small number of applications of asbestos paper will suffice as an insulator. Several thicknesses are necessary to make a covering equal in this respect to the bare tin.

(5) The accumulation of dust and dirt on the pipes does not greatly alter the amount of the loss.

(6) The heat loss from warm-air furnace pipes covered with one layer of asbestos paper is a serious item in the cost of heating, amounting to more than 5 per cent of the coal consumption, depending upon the number and size of the pipes used.

(7) The fact that pipes are partly protected from convection currents of air by joists and studding does not greatly affect the loss.

(8) *Unless the insulation excels the uncovered bright tin in heat insulation properties it should not be used.*

(9) Such materials are available and the tests have shown their merits.

II. THE TESTING EQUIPMENT.

The report mentioned in paragraph 2, which was made at Columbus, Ohio, gave the results of tests on the Auxiliary Testing Plant (see Fig. 6).* It was difficult to obtain entirely satisfactory data on this plant because of the variation in the velocity of the air flowing up the leader and the difficulty of correctly measuring the temperature of the air, as described later in this bulletin. It was therefore decided that a special apparatus should be devised which would eliminate possible errors in temperature measurements.

5. *Description.*—The apparatus here described, (Figs. 1 and 2) was the one used in the tests reported in this bulletin. It consisted of low pressure steam heated drums, five in number, surrounding a central steam header from which the drums drew their supply of steam. The drums were accurately uniform in size, ten inches in diameter by twenty inches in length and were made of sheet metal of the kind to be tested. Steam was condensed in the drums by the cooling action of the air surrounding them and was discharged through water seals connected to each drum. These seals were U-tubes made of pipe, and were long enough to contain a water head of four feet. As the steam condensed the seals became filled with water; the condensate then dripped over into receivers as fast as it accumulated. The water in the seals cooled to room temperature before it dripped into the receivers so that evaporation was not influenced by the heat of the water in the receivers. Each receiver was mounted on a small weighing scales accurate to one one-hundredth pound.

A mercury manometer was used to obtain the pressure of the steam in the central header, and since the temperature of the steam for any known pressure may be taken directly from steam tables, it was possible to determine the temperature of the medium within the drum with great accuracy. A pressure regulator in the steam supply line held the pressure constant within a small fraction of a pound, about 0.2 pound being the variation during a test; as the temperature change for the pressure variation was negligible, the temperatures were uniform and accurate within one degree.

---

* University of Illinois Engineering Experiment Station, Bulletin No. 112, "A Report of Progress in Warm-Air Furnace Research," by Prof. A. C. Willard, pp. 45-49.

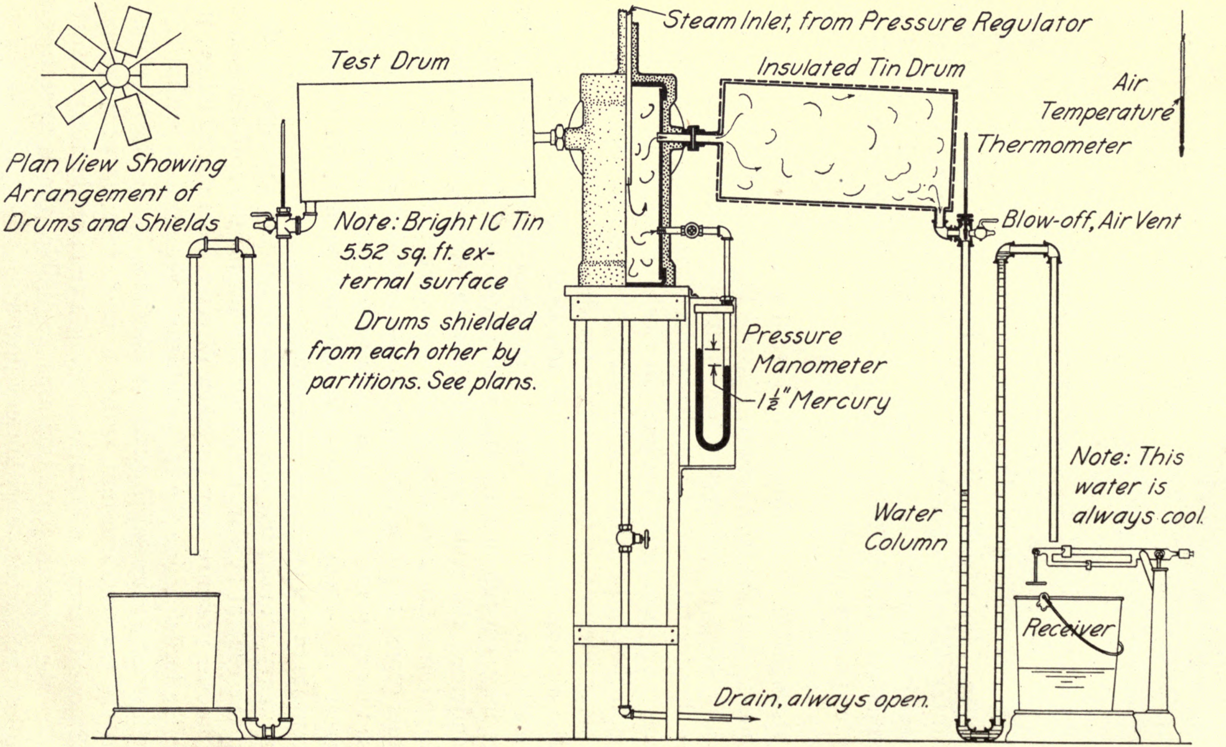

Plan View Showing Arrangement of Drums and Shields
Test Drum
Steam Inlet, from Pressure Regulator
Insulated Tin Drum
Air Temperature Thermometer
Blow-off, Air Vent
Note: Bright IC Tin 5.52 sq. ft. external surface
Drums shielded from each other by partitions. See plans.
Pressure Manometer
$1\frac{1}{2}$" Mercury
Note: This water is always cool.
Water Column
Receiver
Drain, always open.

FIG. 1. SECTIONAL ELEVATION OF STEAM DRUM PLANT FOR TESTING SURFACES FOR HEAT EMISSIVITY

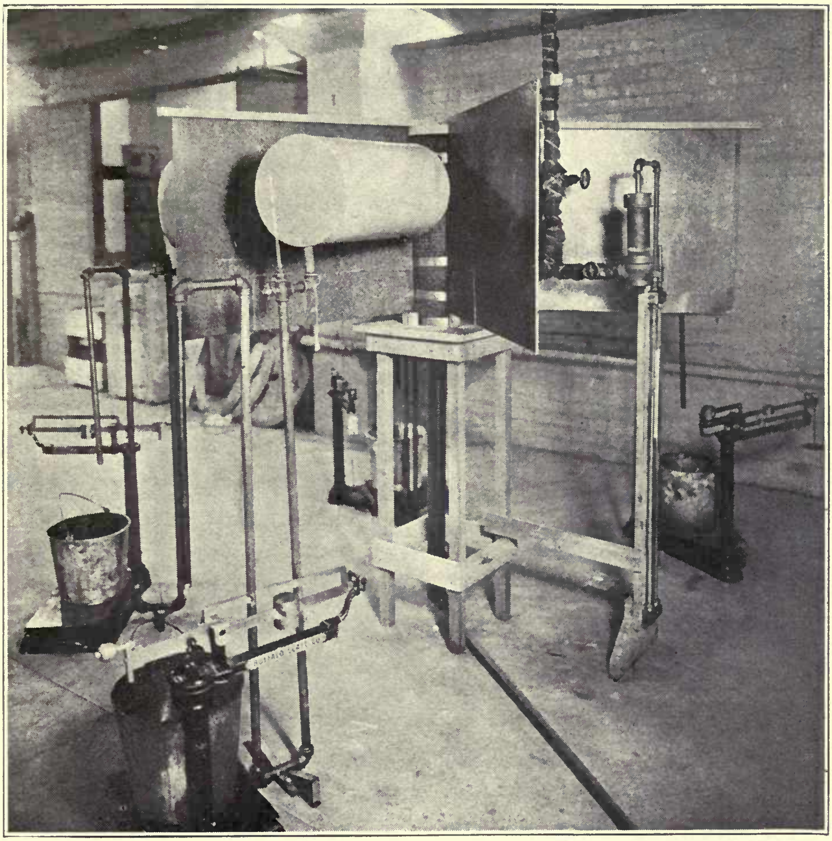


Fig. 2. Photograph Showing the Principal Operative Features of the Steam Drum Plant

No thermometers were required for determining the steam temperature, but one was used in each drum at the point of outlet of the condensate to detect the presence of air in the drums. The readings of these thermometers decreased upon the formation of air pockets in the lower part of the drums or in the connected piping. Air could be blown out of small petcocks located near the thermometers in the piping. No effects on the coefficients were noticeable when steam was allowed to escape for short periods from these petcocks, which could therefore be opened during a test to discharge any small accumulation of air.

The drums were shielded from radiation from each other by blackened compo-board partitions. These partitions did not in any way interfere with the flow of natural air currents. The temperature of the air was measured by thermometers suspended at the elevation of the drums at convenient positions nearby. The thermometers were not affected by radiation from the drums.

Thus, the actual measurements involved were simple and were not liable to serious error. These measurements consisted of the weighing of the steam condensed, the reading of the pressure of the steam, and the reading of the room air temperature.

III. The Tests

6. *Operation.*—The tests reported herein, forty in number, with four drums under steam in each test, were carried out at night when the doors and windows of the large laboratory were closed. No air currents were noticeable near the apparatus. A period of ten hours was chosen for the duration of a test as that time was sufficient to permit accumulations of condensate great enough to render negligible the slight error in weighing. These quantities of water varied from 5 to 20 pounds depending upon the surface material of the test drums. The steam pressure was constant on any given test within 0.2 of an inch head of mercury. In all the tests there was only one case in which the thermometers indicated the presence of air in the drums at the end of ten hours operation. The greatest variation of temperature of the surrounding atmosphere during any night was four degrees Fahrenheit. A recording thermometer was used to show the uniformity of the laboratory temperature.

The drums were tested in different positions around the steam header in order to compensate for any irregularity in the flow of steam to the drums or in the currents of air about the drums. As no irregularities were noticeable in the values of the coefficients of emissivity for the various positions, the practice was abandoned after the first four drums were tested in the interchanged positions.

One drum, of bright tin not insulated, was in operation in all tests. Its performance served as an indication of any lack of uniformity in the conditions existing throughout the tests.

In order to make correction for the loss of water by evaporation from the receivers, a receiver of water was balanced on a scales and the loss in ten hours actually determined by weighing. After several trials in which the loss ranged from 0.10 to 0.12 pound it was decided to use the value 0.11 pound. This amount was applied as a correction to all the weights of water. Every test was repeated until the results obtained were found to agree within very small limits. In no case are the data reported, the result of less than two tests, and in most cases four were run. Two tests were considered sufficient if the results agreed within one per cent of their mean value.

7. *Specimens Tested.*—A complete list of the drums tested is given in Figs. 5 and 5*a*. In the list will be found a description of the insulation or the surface material, the actual area of the drum exposed to the steam, and an abstract number assigned to the drum (which will be useful in connecting the description with the results reported later in this paper). Fig. 4 shows sections through some of the insulations which were of complex construction.

IV. The Calculations

In calculating the coefficients of emissivity for the various surfaces it was assumed that heat of the vapor was entirely given up, upon condensation, to the air through the walls of the containers and the connected piping. Tests on the low pressure steam-line supplying the drums show a steam quality of over 99 per cent. The expression for the coefficient is, therefore, calculated as follows:

$$K_1 = \frac{rW}{A\,(t_s - t_a)} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

in which, K_1 = B. t. u. per sq. ft. per hr. per 1 degree F.
r = latent heat of one lb. of the steam.
W = weight of condensate per hour.
t_s = temperature of the steam.
t_a = temperature of the surrounding air.
A = area of the drum exposed to the steam.

Correction must be made for the loss of heat through the half-inch pipe of which the water seal was made. This loss is not accounted for in the calculation for K_1 above. Three lineal feet of the half-inch pipe were exposed to the steam. The correction is made by using a coefficient of emissivity for this pipe of 2.50 B. t. u. per sq. ft. per hr. per 1 degree F. and the exposed area of 0.375 sq. ft., or, 2.50x0.375 = approximately 1.00 B. t. u. per hr. per 1 degree F. to be subtracted from the heat loss, or,

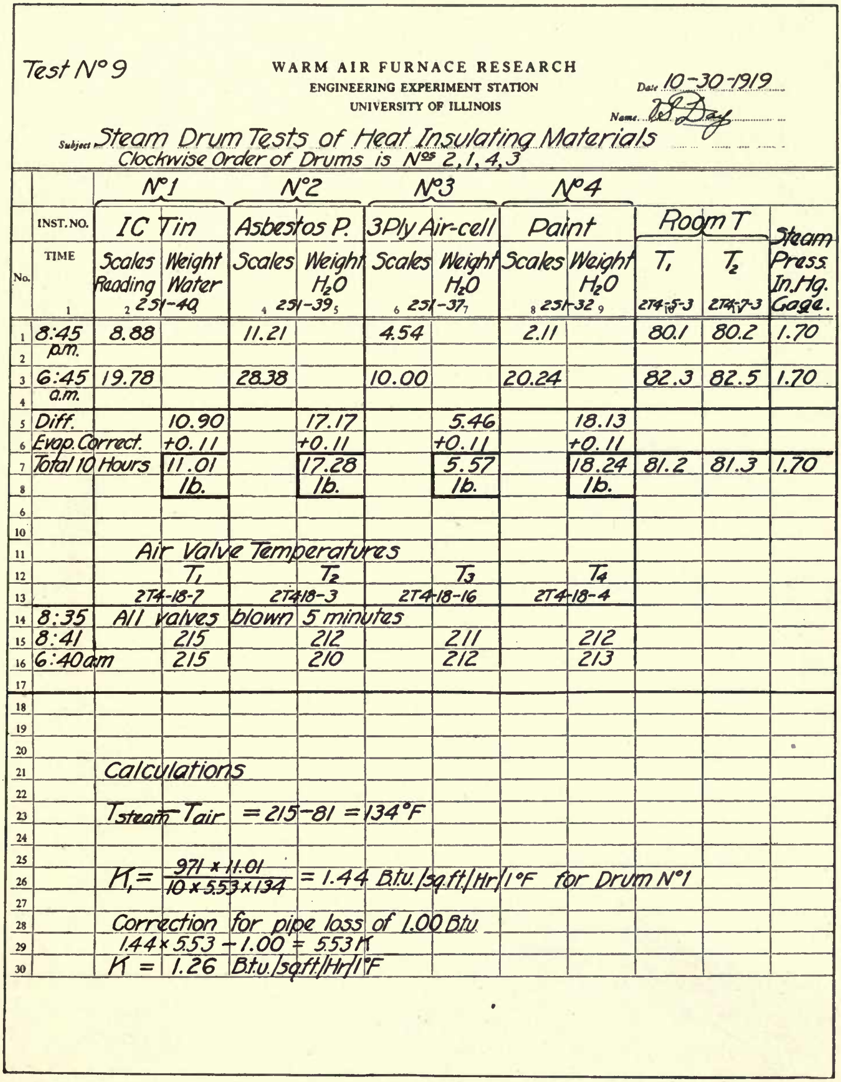
$$AK_1\,(t_s - t_a) - 1.00\,(t_s - t_a) = AK\,(t_s - t_a)$$

and

$$K \text{ corrected} = \frac{AK_1 - 1.00}{A} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

This correction was verified by tests made on the drums with the water seals heavily insulated with hair felt. The values of K so determined agree closely with the values obtained by applying the correction.

Fig. 3 is a copy of a test data sheet and shows all readings and calculations for one test.



Test N° 9

WARM AIR FURNACE RESEARCH
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

Date 10-30-1919
Name Day

Subject Steam Drum Tests of Heat Insulating Materials
Clockwise Order of Drums is N^os 2, 1, 4, 3

		N°1		N°2		N°3		N°4				
	INST. NO.	IC Tin		Asbestos P.		3Ply Air-cell		Paint		Room T		Steam Press. In.Hg. Gage.
No.	TIME 1	Scales Reading 2	Weight Water 3	Scales 4	Weight H_2O 5	Scales 6	Weight H_2O 7	Scales 8	Weight H_2O 9	T_1 10	T_2 11	
		251-40		251-39		251-37		251-32		2T4-5-3	2T4-7-3	
1	8:45	8.88		11.21		4.54		2.11		80.1	80.2	1.70
2	p.m.											
3	6:45	19.78		28.38		10.00		20.24		82.3	82.5	1.70
4	a.m.											
5	Diff.		10.90		17.17		5.46		18.13			
6	Evap. Correct.		+0.11		+0.11		+0.11		+0.11			
7	Total 10 Hours		11.01		17.28		5.57		18.24	81.2	81.3	1.70
8			lb.		lb.		lb.		lb.			
6												
10												
11		Air Valve Temperatures										
12			T_1		T_2		T_3		T_4			
13			2T4-18-7		2T4-18-3		2T4-18-16		2T4-18-4			
14	8:35	All valves blown 5 minutes										
15	8:41		215		212		211		212			
16	6:40 am		215		210		212		213			

Calculations

$T_{steam} - T_{air} = 215 - 81 = 134°F$

$K_1 = \frac{971 \times 11.01}{10 \times 5.53 \times 134} = 1.44$ Btu./sq.ft./Hr./1°F for Drum N°1

Correction for pipe loss of 1.00 Btu

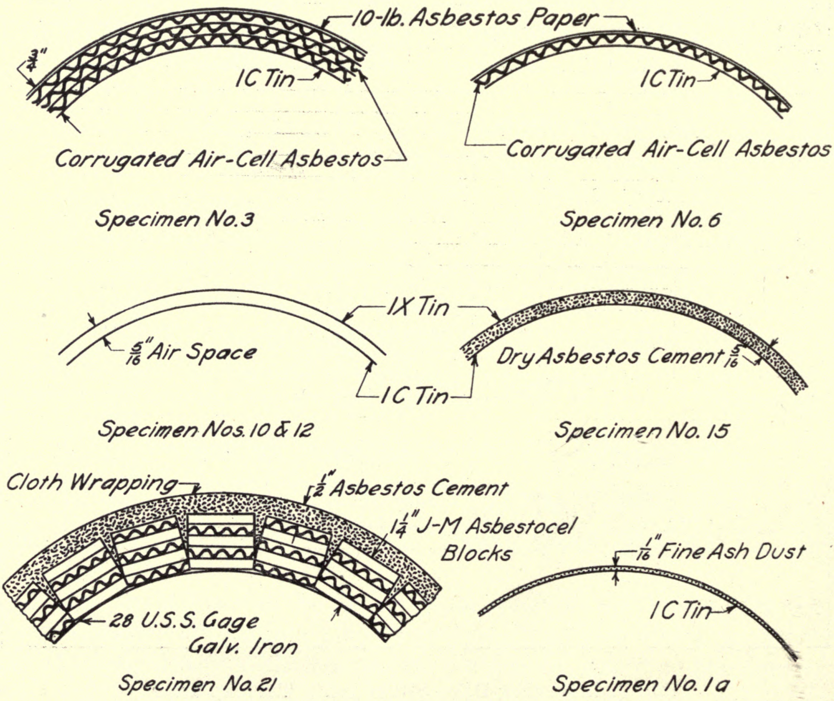
$1.44 \times 5.53 - 1.00 = 5.53 K$

$K = 1.26$ Btu./sq.ft./Hr./1°F

FIG. 3. A SAMPLE DATA SHEET FOR A TYPICAL TEST

V. Results of the Tests

8. *Discussion.*—The significance of the tests will be best understood by a study of the information presented in the diagrammatic chart, Figs. 5 and 5*a*. The heavy black bars afford a graphic comparison of the heat emitting value of the various surfaces. Reference must be made to the descriptive list of drums in order to connect the data with particular test specimens. The relative efficiencies of the various surfaces as heat insulators are given in the next to the last column of the chart. The coefficient for bright IC tin was used as the basis for this comparison.


10-lb. Asbestos Paper
3/4"
IC Tin
Corrugated Air-Cell Asbestos
IC Tin
Corrugated Air-Cell Asbestos
5/16" Air Space
IX Tin
IC Tin
Dry Asbestos Cement 5/16"
Cloth Wrapping
1/2" Asbestos Cement
1 1/4" J-M Asbestocel Blocks
28 U.S.S. Gage Galv. Iron
1/16" Fine Ash Dust
IC Tin

Specimen No. 3

Specimen No. 6

Specimen Nos. 10 & 12

Specimen No. 15

Specimen No. 21

Specimen No. 1a

Fig. 4. Sections Showing Construction of Some of the Complex Surface Coverings

The first result of importance is the convincing evidence which the tests present as an argument against the use of thin layers of asbestos paper covering on bright tin pipes. The heat loss was 39 per cent greater with one thickness of the paper than without. Such a loss is of no small degree of importance as calculations will show that it results in a waste of 5 per cent or more of the coal consumed in the average house furnace.

The fact that the heat loss from the warm-air pipes of a furnace system is of some consequence is not appreciated generally. A considerable part of the heat of the air flowing through the pipes of the average installation is dissipated from the pipe surface to the surrounding air and nearby objects. The insert in Fig. 6 sets forth the results of tests made to determine the amount of this loss. The tests were carried out on a single leader pipe furnace,* see Fig. 6, in which the quantity of air handled and the heat content of the same above the entering temperature could be readily ascertained. The heat loss was determined by calculation from the drop in temperature of the air in its passage through the pipe. The temperature and velocities indicated in the curves are fair representative values.

The significance of these preliminary tests is to bring out the fact that the heat loss from warm-air furnace pipes is a serious item. From the curves, it can be seen that in the case of the asbestos paper-covered pipes, the loss amounts to about 23 per cent of the heat of the air at the bonnet, above inlet air temperature. If the pipe is of bright tin and not covered, this loss is reduced to about 17 per cent of the heat available. In either case the loss is great; and with the further consideration that a warm-air furnace under average conditions of installation is, at best, only about 60 per cent efficient, it will be understood that the actual waste of coal ascribable to poor heat pipe insulation is enough to warrant attention.

The attempt was made in the steam drum tests to determine the effect upon the heat loss of having the drum partly enclosed so that free circulation of the air about the drum would be prevented. The experiment simulated the effect of running leader pipes between joists. The results of these tests as shown in No. 14 and No. 14*a* indicated a slight decrease in the value of *K* for the enclosed drum.

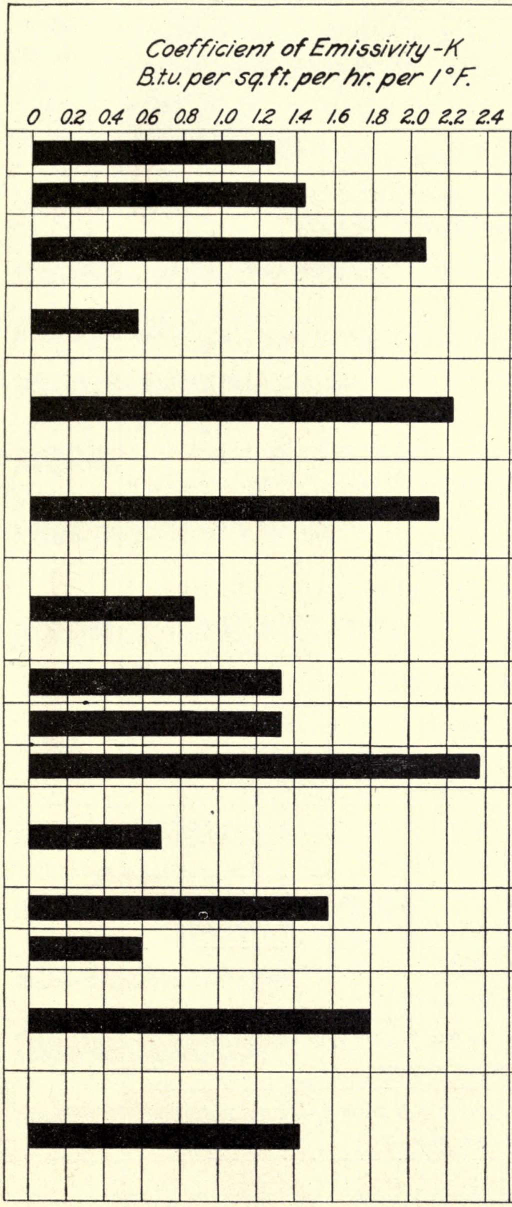
The argument has been advanced that if bright tin pipes were used without covering, they would soon become fouled with dirt and

---

* University of Illinois Engineering Experiment Station Bulletin No. 112, "A Report of Progress in Warm-Air Furnace Research," by Prof. A. C. Willard.

Drum Number	Description of Surface	Area Exposed to Steam sq. ft.
1	IC tin, not insulated, bright	5.53
1a	Same as No. 1 with ash dust sifted on $\frac{1}{16}$" deep	5.53
2	IC tin with 1 thickness of 10-pound asbestos paper	5.52
3	IC tin with 3 thicknesses of air-cell asbestos and 1 thickness of 10-pound asbestos paper	5.50
4	IC tin with 2 applications of gray paint, (of zinc, linseed oil, and lithpone composition)	5.51
5	IC tin with 1 thickness of asbestos paper and 2 applications of paint, (No. 2 drum with same kind of paint as used on No. 4)	5.52
6	IC tin with 1 thickness of air-cell asbestos and 1 thickness of 10 pound asbestos paper, (No. 3 drum used.)	5.50
7	IC tin nickel plated and polished	5.54
8	Galvanized iron, No. 28 U.S.S. gage	5.53
9	Black iron, No. 28 U.S.S. gage, very rusty	5.52
10	Surface and drum No 3 with IX tin casing surrounding, with $\frac{5}{16}$" air-space and with 6 $\frac{1}{2}$" vent holes cut in the casing	5.50
11	IC tin (drum No. 1) coated with Bakelite lacquer	5.53
12	Same as No. 10 but with vents stopped	5.50
13	IC tin (drum No. 2) with 1 thickness of 10-pound asbestos paper and a surface of glaze finish printers' proofing paper	5.52
14	IC tin drum No. 4 with paint removed and a housing of compo-board construction, to represent joists, built around same. Housing 8" deep by 14" wide by 28" long	5.51

FIG. 5. DIAGRAMMATIC TABLE OF THE RESULTS OF

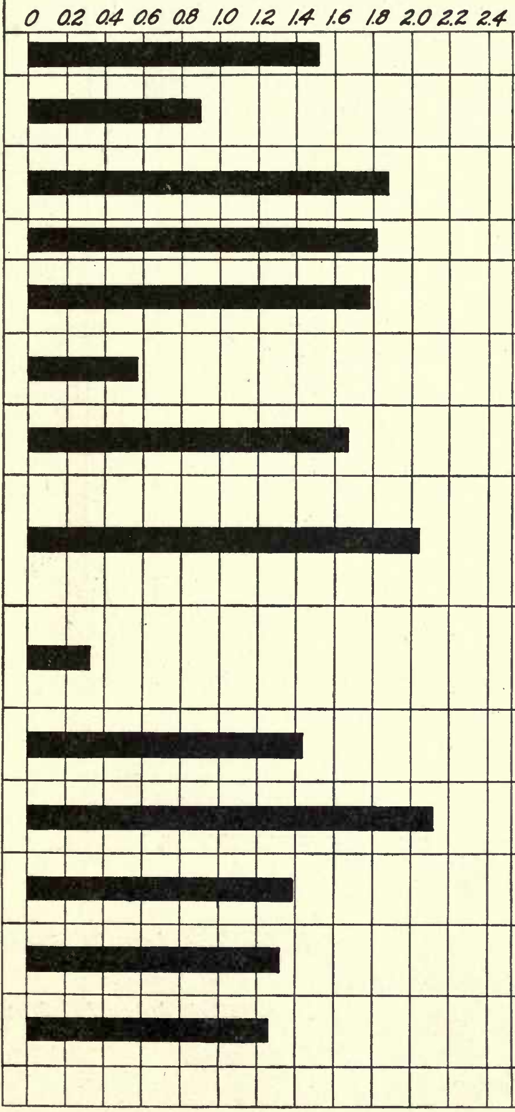


Coefficient of Emissivity-K B.t.u. per sq. ft. per hr. per 1°F.	Relative Efficiency Per Cent	Drum Number
1.280	100.0	1
1.440	89.0	1a
2.080	61.5	2
0.565	226.0	3
2.225	57.5	4
2.155	59.5	5
0.870	147.0	6
1.330	96.0	7
1.330	96.0	8
2.370	54.0	9
0.700	183.0	10
1.575	81.5	11
0.593	216.0	12
1.800	71.0	13
1.430	89.5	14

One Hundred Sixty Tests on Steam Drums

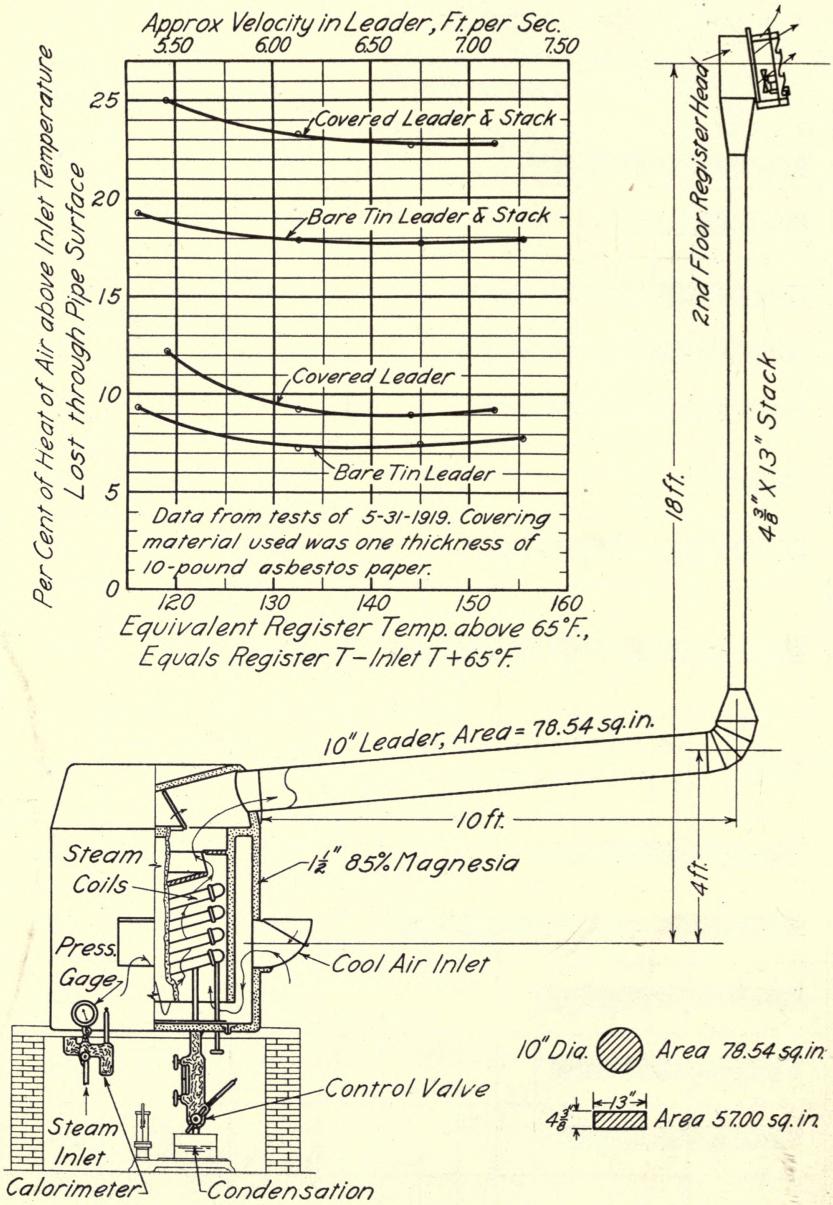
Drum Number	Description of Surface	Area Exposed to Steam sq.ft.
14a	Same as No. 14 with housing removed	5.51
15	Same as No. 10 but with the air-space packed with dry JM asbestos cement	5.50
16	IC tin with 2 thicknesses of 12-pound asbestos paper	5.52
16a	Same as No. 16 with ash dust sifted on $\frac{1}{16}$" deep	5.52
17	IC tin (drum No. 2) with 3 thicknesses of 12-pound asbestos paper	5.52
18	Galvanized iron (drum No. 8) with 3 thicknesses of air-cell asbestos and 1 of 12-pound paper	5.53
19	IC tin (drum No. 2) with 4 thicknesses of 12-pound asbestos paper	5.52
20	IC tin with 1 thickness of asbestos paper covered with a firm coating of white calcimine, (for determining the effect of light and dark surfaces)	5.51
21	Galvanized iron (drum No. 8) with $1\frac{1}{4}$" Asbesto-cel blocks covered with $\frac{1}{2}$" of asbestos cement and a cheesecloth wrapper	5.53
22	IC tin (drum No. 2) with 5 thicknesses of 12-pound asbestos paper	5.52
23	Same as drum No. 20 with lampblack calcimine on the surface used in that test	5.51
24	IC tin (drum No. 2) with 6 thicknesses of 12-pound asbestos paper	5.52
25	IC tin (drum No. 2) with 7 thicknesses of 12-pound asbestos paper	5.52
26	IC tin (drum No. 2) with 8 thicknesses of 12-pound asbestos paper	5.52

Fig. 5a. Continuation of the Diagrammatic Table of the



Coefficient of Emissivity-K B.t.u. per sq. ft. per hr. per 1° F.	Relative Efficiency Per Cent	Drum Number
1.520	84.3	14a
0.899	142.0	15
1.880	68.1	16
1.820	70.5	16a
1.790	71.5	17
0.577	222.0	18
1.670	76.5	19
2.050	62.5	20
0.326	392.0	21
1.435	89.0	22
2.120	60.5	23
1.390	92.0	24
1.320	97.0	25
1.260	101.5	26

Results of One Hundred Sixty Tests on Steam Drums



Data from tests of 5-31-1919. Covering material used was one thickness of 10-pound asbestos paper.

FIG. 6. ELEVATION OF AUXILIARY FURNACE PLANT WITH INSERT SHOWING PERCENTAGE OF HEAT LOST FROM COVERED AND FROM BARE BRIGHT TIN PIPES

dust and so rendered less efficient heat carriers than asbestos paper covered pipes. The fallacy of this argument is revealed by tests No. 1*a* and No. 16*a*. In these tests fine ash dust was sifted on the test drums, one of bare bright tin and the other asbestos paper covered. The dust was more than one-sixteenth inch deep on top of the drums. The results as shown in tests No. 1*a* and No. 16*a* of the chart indicate that the bare tin suffered a loss of 11 per cent in efficiency whereas the asbestos paper surface improved 2.4 per cent. There still remained, however, a difference of 25 per cent in favor of the bare tin pipe.

In order to demonstrate further the inefficacy of thin layers of asbestos paper as a heat insulator, tests were run in which the number of thicknesses of paper was increased until the heat loss became less than the loss through a bare bright tin specimen. The curve (Fig. 7) gives the results of these tests. Eight thicknesses of the twelve-pound paper were applied before the desired result was obtained. In these tests the moistened paper was wrapped tightly and shrunk on the drums so that only a small quantity of air was entrapped between the successive layers of paper. The total thickness of paper was two-

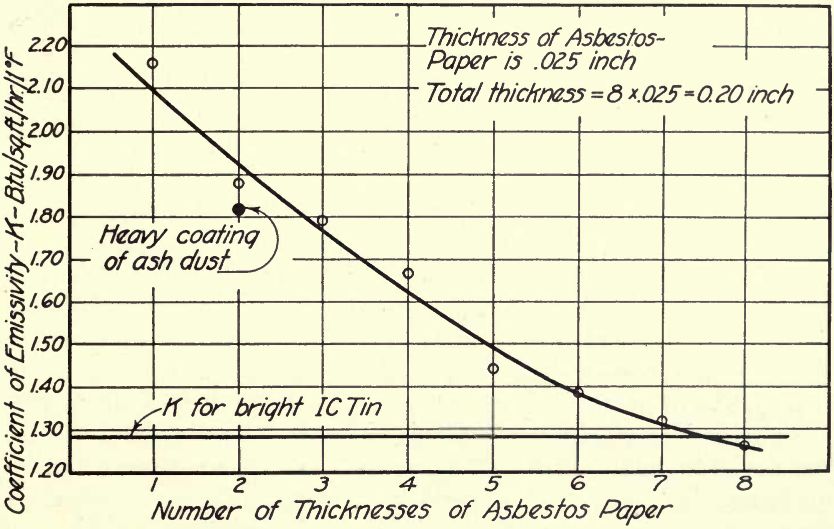


FIG. 7. CURVES SHOWING INEFFECTIVENESS OF COMMERCIAL ASBESTOS PAPER FOR INSULATION OF BRIGHT TIN PIPES

tenths of an inch. The impractical features of such a method of insulating are of course evident. The use of thin layers of asbestos paper on bright tin pipes must be abandoned if the best results are to be obtained in furnace heating.

Other materials of better heat insulating value than the bare tin were tested. Numbers 3, 6, 10, 12, 15, 18, and 21, all show values which indicate that a large saving would be effected by their use. Some of them are expensive and not easy of application, but good selections may be made. The air-cell combinations Nos. 3 and 6 are excellent insulators, are easy to fit to basement leaders, are not expensive, and the latter, in particular, is not bulky.

The double wall tin pipes Nos. 10 and 12 are very efficient insulators and are easy to construct and to install. Other tests are in progress which are expected to establish still further the merits of this type.

The tests on galvanized iron specimens brought out the fact that the heat loss through this material is not greater than through bright tin of the same gage. This low heat radiating property is an argument in favor of the galvanized iron leader pipe. Nos. 18 and 21 are good insulations for the exterior of furnace casings, the heat loss through the latter being almost negligible. No. 21 is very easily applied.

The tests on drum No. 11 were made to determine the effect of transparent applications on the tin surface. Bakelite lacquer was used. The result was a slight increase in the heat loss. It was thought that the use of the lacquer would be justified in practice by its rust preventing qualities, but specimens exposed to steam laden air for long periods show no advantage for the protective coating.

Tests Nos. 20 and 23 were made for the purpose of ascertaining the effect of color upon the heat radiating value of a surface. Applications of white calcimine were made on a drum which was tested; then a coat of dull black calcimine was added and the drum re-tested; a final coating of white calcimine was applied and the drum again tested. The alternate tests with white calcimine checked very closely proving that the additional thickness of the calcimine was not sufficient to have any bearing on the results. Beyond demonstrating the superior radiating value of a dark surface, the tests have little significance.

Specimens Nos. 4 and 5 demonstrated the uneconomical effect due to increased heat loss of any kind of oil paint applications on heat pipes. A comparison of Nos. 1 and 4 will show the enormous increase in heat loss caused by painting bright tin heat pipes, and a comparison of Nos. 2 and 5 will show the similar wasteful effect of painting over the asbestos paper covering. However, the use of paint on asbestos paper has in its favor the moisture-proofing effect of the paint.

Other information of value may be found in the data given in the table. To use these data for the determination of the approximate heat loss from a heat pipe, it is only necessary to multiply the value of K for the surface by the surface area of the pipe exposed and further multiply by the difference in temperature between the air inside and outside the pipe, or,

$$\text{B. t. u. loss per hour} = K \text{ x Area in sq. ft. x } (t_1 - t_a)$$

On account of the difficulty of correctly measuring the temperature of the air near the inner surface of the pipe, the method of determining the loss from a pipe as here given, is only approximate.

VI. CORROBORATIVE TESTS

9. *The Auxiliary Air Plant.*—In order to show the connection between the work done on the steam drums already described and conditions obtaining in a warm-air system, the following account of experiments conducted on the Auxiliary Furnace Plant* which is shown in Fig. 6 of this bulletin is given. In these experiments, the weight of air flowing up the pipe was determined by the use of the steam-air meter which supplied the heat. Half way along the ten-foot length of the ten-inch leader pipe was located a traversing device (Fig. 8) which made it possible to get temperatures at any point across

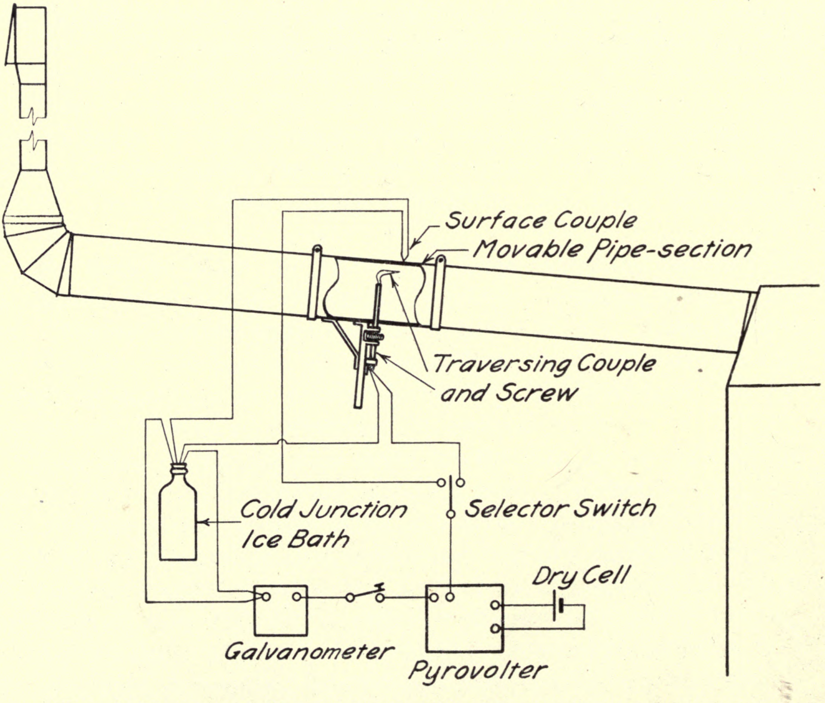


FIG. 8. DIAGRAM OF THERMOCOUPLE CONNECTIONS TO THE AUXILIARY TESTING PLANT

the pipe diameter by intervals of one-hundredth of an inch. A thermocouple was used in the traverse and its readings were accurate within one degree Fahrenheit. A second couple was tinned to the surface of the pipe and by rotation of the pipe (a short section could be turned) temperatures at any point on the surface in the plane of rotation of the couple could be determined.

---

* University of Illinois Engineering Experiment Station Bulletin No. 112, "A Report of Progress in Warm-Air Furnace Research," by Prof. A. C. Willard.

10. *Temperature Measurement.*—The couples used in this work were made of copper and constantan wires of No. 22 gage. The junctions were silver soldered. Fig. 8 shows the wiring arrangement and the instruments used for two couples. As many couples may be used as there are contact points on the selector switch. Four were used on the leader pipe for the tests here described. The couples were calibrated individually in a hot oil bath over a range of 200 degrees, and calibration curves were carefully drawn. It is possible to repeat readings of the pyrovolter within 0.01 millivolt which by calibration is 0.4 degree Fahrenheit. This insures an accuracy of reading of one-half degree. As the couples were soldered to the surface of the pipe in some parts of the work, it was thought advisable to repeat the calibration after the couples were removed from the pipe. The constancy of the couples was found to be unaltered by the soldering to the pipe.

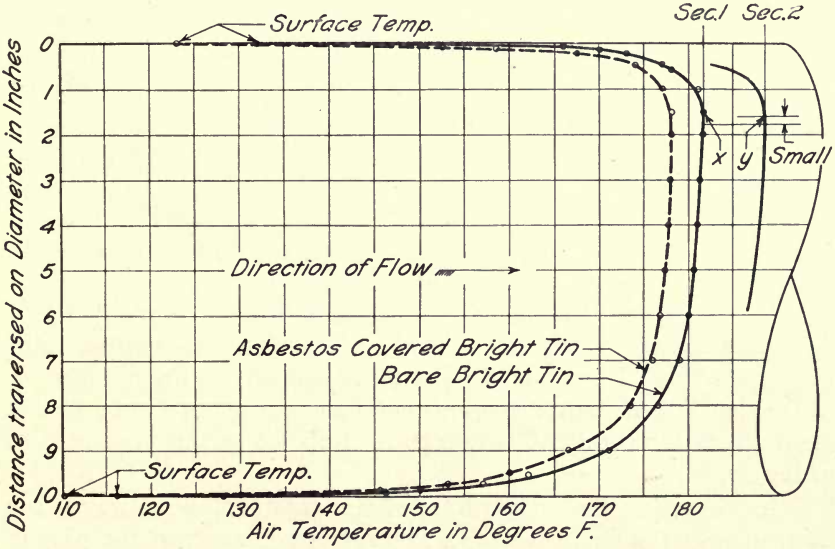


FIG. 9. TEMPERATURE TRAVERSE CURVES OF TEN-INCH LEADER PIPE

The use of thermometers for accurate temperature measurements in an air stream is not satisfactory. Thermometer readings will not be in agreement with thermocouple readings though both are suspended in close proximity in the same stream of moving air. For this reason thermocouples were used throughout these tests.

In Fig. 9 are given temperature traverse curves showing the variation in temperature across the ten-inch pipe. Curves are shown for both the asbestos paper-covered pipe and the bare pipe, all other conditions of the tests being identical. The curves demonstrate the heat-radiating value of the asbestos paper. Note that not only the air temperature but the surface metal temperature beneath the paper is lower in the case of the covered pipe, this fact indicating that the tin is conducting the heat to the asbestos covering which in turn radiates it more rapidly than does uncovered tin. Very exact means were taken to determine the temperature of the film of air in contact with the inner surface of the pipe. The traversing couple, made of wire 0.025 inch in diameter, was filed flat at the junction so that it was less than 0.02 inch thick. Measurements of the temperature were made with this thin couple at a distance from the pipe surface just great enough to cause a break in an electric circuit through the couple and the pipe, the break being indicated by a small voltmeter in the circuit. The distance was less than 0.01 inch from the pipe surface. The temperatures were found to differ from the metal temperature 15 to 30 degrees, the greater difference existing in the case of asbestos paper-covered pipe. (See the sample data sheet Fig. 10 for data on these measurements.)

The temperature change of the air flowing in the pipe was determined by the use of couples suspended in the air stream three inches below the top of the pipe. These couples correctly register the temperature drop of the mass of air between any two sections for the reason that the traverse curves are similar in shape at all sections along the pipe, and the error in reading the temperature due to a difference in the traverse curve is very slight. This fact is illustrated in Fig. 9 at Sec. 1 and Sec. 2. It will be seen that a great difference in the shape of the traverse curve would be necessary to cause serious error in determining the temperature drop along the path of flow of the air.

In measuring the temperature of the pipe surface, it was found that, whereas the air in the pipe dropped in temperature, the pipe itself showed a measurable increase in temperature away from the

WARM AIR FURNACE RESEARCH
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

Date 2-17-1920
Name V. S. Day

Auxiliary Plant
Subject Temperature Traverse Test of 10" Leader.
10"x10' Leader not covered, 8 4⅜"x13"x14' Stack

		Temp. Traverse				Air Temp.		Metal Temp.			Weight	
	INST. NO.											
No.	TIME 1	Thermocouple Position 2	Reading 3	Temp. °F 4	Room T °F 5	Couple Reading 6	Temp. °F 7	Couple Reading 8	Temp. °F 9	10	11	12
1	Traversing Upward	Contact										
2		.01	2.89	156	68	At Bonnet		At Bonnet			Time	Scales
3		.06	3.10	164		3.70	187	2.06	122.5		1:55	3.68
4		.11	3.16	166							2:55	28.62
5		.21	.25	169.5							Diff.	24.94
6		.26	.28	170.5		At 2 Ft. Out		At 2 Ft. Out			St. Press.	137 Lb.
7		.36	.29	171		3.66	185	2.10	124		Barometer	
8		.56	.35	173.5							= 29.60"Hg.	
6		.76	.39	174.5								
10		.96	.42	176		At 5 Ft. Out		At 5 Ft. Out				
11		1.46	.51	179		3.60	183	2.12	125			
12		1.96	.51	179								
13		2.46	.56	181								
14		3.46	.57	181.5		At 8 Ft. Out		At 8 Ft. Out				
15		3.96	3.59	182	68	3.49	179	2.14	126			
16	Traversing Downward	Contact										
17		.01	3.10	164	68							
18		.06	.29	171		At Boot		At Boot				
19		.11	.34	173		3.42	176					
20		.21	.47	178								
21		.26	.49	178.5								
22		.36	.55	180.5								
23		.56	.58	181.5								
24		.76	.63	183.5								
25		.96	.66	185								
26		1.46	.66	185								
27		1.96	.67	185.5								
28		2.46	.65	184.5								
29		3.46	.65	184								
30		4.46	3.64	184	68							

Weight Air per Hr. by Steammeter

$$= \frac{(1188 + 32 - 340) \times 0.95 \times 24.94}{0.24 \times (187 - 68)} = 730 \text{ Lb.}$$

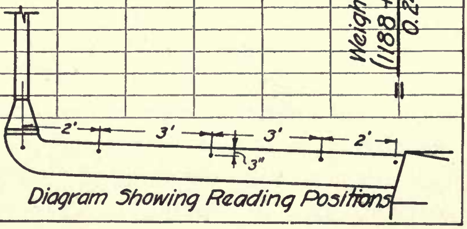


Diagram Showing Reading Positions

FIG. 10. DATA FOR A TEMPERATURE TRAVERSE TEST ON THE AUXILIARY FURNACE TESTING PLANT

furnace. This slight increase occurred when the pipe was covered as well as when bare. As this increase amounted to only about 3 degrees and was proportional to the length of pipe, it was considered permissible to use the temperature half way up the leader as the mean metal temperature.

11. *Calculation.*—The coefficient of emissivity for the pipe surface may be calculated since the heat loss through the surface of the pipe between any two sections is equal to the decrease in the heat content of the air in its passage through the length of pipe between the two sections, or,

$$0.24\ W\ (t_1 - t_2) = A\ (t_s - t_a)\ K_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

in which *W* is the weight of air flowing.

$t_1 - t_2$ = the temperature drop of the air in the given length of pipe.
A = the area of the pipe exposed in the given length of pipe.
$t_s - t_a$ = the drop in temperature between the metal of the pipe and the air.
K_2 = the coefficient of emissivity not corrected.

Solution of the equation will furnish a value for K_2, which will not, however, check or agree with the value determined in the steam drum tests of the same material. The variation may be easily explained since it is a well-established law that the coefficient of heat emissivity of a hot body varies with the temperature difference between the heating and the cooling medium. (See tests of radiators by J. R. Allen which demonstrate this fact).*

In the case of the heat pipe the temperature traverse showed a low air temperature near the inner surface of the pipe and also a correspondingly low temperature of the metal of the pipe. The result is a comparatively low value of $t_s - t_a$ and according to the law, a low coefficient is to be expected.

The following case will illustrate: the pipe was covered with 12-pound asbestos paper. The surface couple showed that the temperature of the tin beneath the paper was actually lower than the temperature in the case of a bare pipe.

---

* Paper by J. R. Allen, given before American Society of Heating and Ventilating Engineers, Jan. 28, 1920.

$$W = 479$$
$$t_1 - t_2 = 17$$
$$t_s - t_a = 44$$
$$A = 26.40$$

$$K_2 = \frac{479 \times 0.24 \times 17}{44 \times 26.40} = 1.77 \text{ B. t. u. per sq. ft. per hr. per 1 degree F.}$$

Assuming that the correction of 0.2 per cent per degree F. below the standard range of 150 degrees which is used in making corrections with direct radiators, applies to this surface,* the value of K becomes:

$$K_2 = K - 0.002\, K\, [150 - (t_s - t_a)]$$
$$1.77 = K\, [1 - 0.002\, (150 - 44)]$$
$$K = 2.24 \text{ B. t. u. per sq. ft. per hr. per 1 degree F.}$$

This result is in close agreement with the value of K = 2.08 as determined in the steam drum tests, and reported above.

12. *Conclusion.*—Enough tests have been made on this apparatus to entirely corroborate the results obtained on the steam drums, and additional tests are in progress in which more exacting methods are employed.†

---

* "Mechanical Equipment of Buildings," by Harding and Willard, Vol. 1, p. 78.

† For further information regarding the tests involving the use of thermocouples on this plant, see University of Illinois Engineering Experiment Station Bulletin No. 112, "A Report of Progress in Warm-Air Furnace Research," by Prof. A. C. Willard. An abstract of this bulletin was presented at the Annual Meeting of the American Society of Heating and Ventilating Engineers, at New York, January 28, 1920.

LIST OF
PUBLICATIONS OF THE ENGINEERING EXPERIMENT STATION

Bulletin No. 1. Tests of Reinforced Concrete Beams, by Arthur N. Talbot. 1904. *None available.*

Circular No. 1. High-Speed Tool Steels, by L. P. Breckenridge. 1905. *None available.*

Bulletin No. 2. Tests of High-Speed Tool Steels on Cast Iron, by L. P. Breckenridge and Henry B. Dirks. 1905. *None available.*

Circular No. 2. Drainage of Earth Roads, by Ira O. Baker. 1906. *None available.*

Circular No. 3. Fuel Tests with Illinois Coal (Compiled from tests made by the Technological Branch of the U. S. G. S., at the St. Louis, Mo., Fuel Testing Plant, 1904-1907), by L. P. Breckenridge and Paul Diserens. 1908. *Thirty cents.*

Bulletin No. 3. The Engineering Experiment Station of the University of Illinois, by L. P. Breckenridge. 1906. *None available.*

Bulletin No. 4. Tests of Reinforced Concrete Beams, Series of 1905, by Arthur N. Talbot. 1906. *Forty-five cents.*

Bulletin No. 5. Resistance of Tubes to Collapse, by Albert P. Carman and M. L. Carr. 1906. *None available.*

Bulletin No. 6. Holding Power of Railroad Spikes, by Roy I. Webber. 1906. *None available.*

Bulletin No. 7. Fuel Tests with Illinois Coals, by L. P. Breckenridge, S. W. Parr, and Henry B. Dirks. 1906. *None available.*

Bulletin No. 8. Tests of Concrete: I, Shear; II, Bond, by Arthur N. Talbot. 1906. *None available.*

Bulletin No. 9. An Extension of the Dewey Decimal System of Classification Applied to the Engineering Industries, by L. P. Breckenridge and G. A. Goodenough. 1906. Revised Edition, 1912. *Fifty cents.*

Bulletin No. 10. Tests of Concrete and Reinforced Concrete Columns, Series of 1906, by Arthur N. Talbot. 1907. *None available.*

Bulletin No. 11. The Effect of Scale on the Transmission of Heat through Locomotive Boiler Tubes, by Edward C. Schmidt and John M. Snodgrass. 1907. *None available.*

Bulletin No. 12. Tests of Reinforced Concrete T-Beams, Series of 1906, by Arthur N. Talbot. 1907. *None available.*

Bulletin No. 13. An Extension of the Dewey Decimal System of Classification Applied to Architecture and Building, by N. Clifford Ricker. 1907. *None available.*

Bulletin No. 14. Tests of Reinforced Concrete Beams, Series of 1906, by Arthur N. Talbot. 1907. *None available.*

Bulletin No. 15. How to Burn Illinois Coal without Smoke, by L. P. Breckenridge. 1907. *None available.*

Bulletin No. 16. A Study of Roof Trusses, by N. Clifford Ricker. 1907. *None available.*

Bulletin No. 17. The Weathering of Coal, by S. W. Parr, N. D. Hamilton, and W. F. Wheeler. 1907. *None available.*

Bulletin No. 18. The Strength of Chain Links, by G. A. Goodenough and L. E. Moore. 1907. *Forty cents.*

Bulletin No. 19. Comparative Tests of Carbon, Metallized Carbon, and Tantalum Filament Lamps, by T. H. Amrine. 1907. *None available.*

Bulletin No. 20. Tests of Concrete and Reinforced Concrete Columns, Series of 1907, by Arthur N. Talbot. 1907. *None available.*

Bulletin No. 21. Tests of a Liquid Air Plant, by C. S. Hudson and C. M. Garland. 1908. *Fifteen cents.*

Bulletin No. 22. Tests of Cast-Iron and Reinforced Concrete Culvert Pipe, by Arthur N. Talbot. 1908. *None available.*

Bulletin No. 23. Voids, Settlement, and Weight of Crushed Stone, by Ira O. Baker. 1908. *Fifteen cents.*

**Bulletin No. 24.* The Modification of Illinois Coal by Low Temperature Distillation, by S. W. Parr and C. K. Francis. 1908. *Thirty cents.*

Bulletin No. 25. Lighting Country Homes by Private Electric Plants, by T. H. Amrine. 1908. *Twenty cents.*

Bulletin No. 26. High Steam-Pressure in Locomotive Service. A Review of a Report to the Carnegie Institution of Washington, by W. F. M. Goss. 1908. *Twenty-five cents.*

Bulletin No. 27. Tests of Brick Columns and Terra Cotta Block Columns, by Arthur N. Talbot and Duff A. Abrams. 1908. *Twenty-five cents.*

Bulletin No. 28. A Test of Three Large Reinforced Concrete Beams, by Arthur N. Talbot. 1908. *Fifteen cents.*

Bulletin No. 29. Tests of Reinforced Concrete Beams: Resistance to Web Stresses, Series of 1907 and 1908, by Arthur N. Talbot. 1909. *Forty-five cents.*

Bulletin No. 30. On the Rate of Formation of Carbon Monoxide in Gas Producers, by J. K. Clement, L. H. Adams, and C. N. Haskins. 1909. *Twenty-five cents.*

Bulletin No. 31. Tests with House-Heating Boilers, by J. M. Snodgrass. 1909. *Fifty-five cents.*

Bulletin No. 32. The Occluded Gases in Coal, by S. W. Parr and Perry Barker. 1909. *Fifteen cents.*

Bulletin No. 33. Tests of Tungsten Lamps, by T. H. Amrine and A. Guell. 1909. *Twenty cents.*

**Bulletin No. 34.* Tests of Two Types of Tile-Roof Furnaces under a Water-Tube Boiler, by J. M. Snodgrass. 1909. *Fifteen cents.*

---

*A limited number of copies of bulletins starred are available for free distribution.

Bulletin No. 35. A Study of Base and Bearing Plates for Columns and Beams, by N. Clifford Ricker. 1909. *Twenty cents.*

Bulletin No. 36. The Thermal Conductivity of Fire-Clay at High Temperatures, by J. K. Clement and W. L. Egy. 1909. *Twenty cents.*

Bulletin No. 37. Unit Coal and the Composition of Coal Ash, by S. W. Parr and W. F. Wheeler. 1909. *None available.*

Bulletin No. 38. The Weathering of Coal, by S. W. Parr and W. F. Wheeler. 1909. *Twenty-five cents.*

**Bulletin No. 39.* Tests of Washed Grades of Illinois Coal, by C. S. McGovney. 1909. *Seventy-five cents.*

Bulletin No. 40. A Study in Heat Transmission, by J. K. Clement and C. M. Garland. 1909. *Ten cents.*

Bulletin No. 41. Tests of Timber Beams, by Arthur N. Talbot. 1909. *Thirty-five cents.*

**Bulletin No. 42.* The Effect of Keyways on the Strength of Shafts, by Herbert F. Moore. 1909. *Ten cents.*

Bulletin No. 43. Freight Train Resistance, by Edward C. Schmidt. 1910. *Seventy-five cents.*

Bulletin No. 44. An Investigation of Built-up Columns under Load, by Arthur N. Talbot and Herbert F. Moore. 1910. *Thirty-five cents.*

**Bulletin No. 45.* The Strength of Oxyacetylene Welds in Steel, by Herbert L. Whittemore. 1910. *Thirty-five cents.*

Bulletin No. 46. The Spontaneous Combustion of Coal, by S. W. Parr and F. W. Kressman. 1910. *Forty-five cents.*

**Bulletin No. 47.* Magnetic Properties of Heusler Alloys, by Edward B. Stephenson. 1910. *Twenty-five cents.*

**Bulletin No. 48.* Resistance to Flow through Locomotive Water Columns, by Arthur N. Talbot and Melvin L. Enger. 1911. *Forty cents.*

**Bulletin No. 49.* Tests of Nickel-Steel Riveted Joints, by Arthur N. Talbot and Herbert F. Moore. 1911. *Thirty cents.*

**Bulletin No. 50.* Tests of a Suction Gas Producer, by C. M. Garland and A. P. Kratz. 1911. *Fifty cents.*

Bulletin No. 51. Street Lighting, by J. M. Bryant and H. G. Hake. 1911. *Thirty-five cents.*

**Bulletin No. 52.* An Investigation of the Strength of Rolled Zinc, by Herbert F. Moore. 1911. *Fifteen cents.*

**Bulletin No. 53.* Inductance of Coils, by Morgan Brooks and H. M. Turner. 1912. *Forty cents.*

Bulletin No. 54. Mechanical Stresses in Transmission Lines, by A. Guell. 1912. *Twenty cents.*

**Bulletin No. 55.* Starting Currents of Transformers, with Special Reference to Transformers with Silicon Steel Cores, by Trygve D. Yensen. 1912. *Twenty cents.*

---

*A limited number of copies of bulletins starred are available for free distribution.

**Bulletin No. 56.* Tests of Columns: An Investigation of the Value of Concrete as Reinforcement for Structural Steel Columns, by Arthur N. Talbot and Arthur R. Lord. 1912. *Twenty-five cents.*

**Bulletin No. 57.* Superheated Steam in Locomotive Service. A Review of Publication No. 127 of the Carnegie Institution of Washington, by W. F. M Goss. 1912. *Forty cents.*

**Bulletin No. 58.* A New Analysis of the Cylinder Performance of Reciprocating Engines, by J. Paul Clayton. 1912. *Sixty cents.*

**Bulletin No. 59.* The Effect of Cold Weather upon Train Resistance and Tonnage Rating, by Edward C. Schmidt and F. W. Marquis. 1912. *Twenty cents.*

Bulletin No. 60. The Coking of Coal at Low Temperature, with a Preliminary Study of the By-Products, by S. W. Parr and H. L. Olin. 1912. *Twenty-five cents.*

**Bulletin No. 61.* Characteristics and Limitation of the Series Transformer, by A. R. Anderson and H. R. Woodrow. 1912. *Twenty-five cents.*

Bulletin No. 62. The Electron Theory of Magnetism, by Elmer H. Williams. 1912. *Thirty-five cents.*

Bulletin No. 63. Entropy-Temperature and Transmission Diagrams for Air, by C. R. Richards. 1913. *Twenty-five cents.*

**Bulletin No. 64.* Tests of Reinforced Concrete Buildings under Load, by Arthur N. Talbot and Willis A. Slater. 1913. *Fifty cents.*

**Bulletin No. 65.* The Steam Consumption of Locomotive Engines from the Indicator Diagrams, by J. Paul Clayton. 1913. *Forty cents.*

Bulletin No. 66. The Properties of Saturated and Superheated Ammonia Vapor, by G. A. Goodenough and William Earl Mosher. 1913. *Fifty cents.*

Bulletin No. 67. Reinforced Concrete Wall Footings and Column Footings, by Arthur N. Talbot. 1913. *None available.*

Bulletin No. 68. The Strength of I-Beams in Flexure, by Herbert F. Moore. 1913. *Twenty cents.*

Bulletin No. 69. Coal Washing in Illinois, by F. C. Lincoln. 1913. *Fifty cents.*

Bulletin No. 70. The Mortar-Making Qualities of Illinois Sands, by C. C. Wiley. 1913. *Twenty cents.*

Bulletin No. 71. Tests of Bond between Concrete and Steel, by Duff A. Abrams. 1913. *One dollar.*

**Bulletin No. 72.* Magnetic and Other Properties of Electrolytic Iron Melted in Vacuo, by Trygve D. Yensen. 1914. *Forty cents.*

Bulletin No. 73. Acoustics of Auditoriums, by F. R. Watson. 1914. *Twenty cents.*

**Bulletin No. 74.* The Tractive Resistance of a 28-Ton Electric Car, by Harold H. Dunn. 1914. *Twenty-five cents.*

Bulletin No. 75. Thermal Properties of Steam, by G. A. Goodenough. 1914. *Thirty-five cents.*

---

*A limited number of copies of bulletins starred are available for free distribution.

Bulletin No. 76. The Analysis of Coal with Phenol as a Solvent, by S. W. Parr and H. F. Hadley. 1914. *Twenty-five cents.*

**Bulletin No. 77.* The Effect of Boron upon the Magnetic and Other Properties of Electrolytic Iron Melted in Vacuo, by Trygve D. Yensen. 1915. *Ten cents.*

Bulletin No. 78. A Study of Boiler Losses, by A. P. Kratz. 1915. *Thirty-five cents.*

**Bulletin No. 79.* The Coking of Coal at Low Temperatures, with Special Reference to the Properties and Composition of the Products, by S. W. Parr and H. L. Olin. 1915. *Twenty-five cents.*

Bulletin No. 80. Wind Stresses in the Steel Frames of Office Buildings, by W. M. Wilson and G. A. Maney. 1915. *Fifty cents.*

Bulletin No. 81. Influence of Temperature on the Strength of Concrete, by A. B. McDaniel. 1915. *Fifteen cents.*

Bulletin No. 82. Laboratory Tests of a Consolidation Locomotive, by E. C. Schmidt, J. M. Snodgrass, and R. B. Keller. 1915. *Sixty-five cents.*

**Bulletin No. 83.* Magnetic and Other Properties of Iron-Silicon Alloys, Melted in Vacuo, by Trygve D. Yensen. 1915. *Thirty-five cents.*

Bulletin No. 84. Tests of Reinforced Concrete Flat Slab Structures, by Arthur N. Talbot and W. A. Slater. 1916. *Sixty-five cents.*

**Bulletin No. 85.* The Strength and Stiffness of Steel under Biaxial Loading, by A. J. Becker. 1916. *Thirty-five cents.*

Bulletin No. 86. The Strength of I-Beams and Girders, by Herbert F. Moore and W. M. Wilson. 1916. *Thirty cents.*

**Bulletin No. 87.* Correction of Echoes in the Auditorium, University of Illinois, by F. R. Watson and J. M. White. 1916. *Fifteen cents.*

Bulletin No. 88. Dry Preparation of Bituminous Coal at Illinois Mines, by E. A. Holbrook. 1916. *Seventy cents.*

Bulletin No. 89. Specific Gravity Studies of Illinois Coal, by Merle L. Nebel. 1916. *Thirty cents.*

Bulletin No. 90. Some Graphical Solutions of Electric Railway Problems, by A. M. Buck. 1916. *Twenty cents.*

Bulletin No. 91. Subsidence Resulting from Mining, by L. E. Young and H. H. Stoek. 1916. *None available.*

**Bulletin No. 92.* The Tractive Resistance on Curves of a 28-Ton Electric Car, by E. C. Schmidt and H. H. Dunn. 1916. *Twenty-five cents.*

**Bulletin No. 93.* A Preliminary Study of the Alloys of Chromium, Copper, and Nickel, by D. F. McFarland and O. E. Harder. 1916. *Thirty cents.*

**Bulletin No. 94.* The Embrittling Action of Sodium Hydroxide on Soft Steel, by S. W. Parr. 1917. *Thirty cents.*

**Bulletin No. 95.* Magnetic and Other Properties of Iron-Aluminum Alloys Melted in Vacuo, by T. D. Yensen and W. A. Gatward. 1917. *Twenty-five cents.*

---

*A limited number of copies of bulletins starred are available for free distribution.

**Bulletin No. 96.* The Effect of Mouthpieces on the Flow of Water through a Submerged Short Pipe, by Fred B Seely. 1917. *Twenty-five cents.*

**Bulletin No. 97.* Effects of Storage upon the Properties of Coal, by S. W. Parr. 1917. *Twenty cents.*

**Bulletin No. 98.* Tests of Oxyacetylene Welded Joints in Steel Plates, by Herbert F. Moore. 1917. *Ten cents.*

Circular No. 4. The Economical Purchase and Use of Coal for Heating Homes, with Special Reference to Conditions in Illinois. 1917. *Ten cents.*

**Bulletin No. 99.* The Collapse of Short Thin Tubes, by A. P. Carman, 1917. *Twenty cents.*

**Circular No. 5.* The Utilization of Pyrite Occurring in Illinois Bituminous Coal, by E. A. Holbrook. 1917. *Twenty cents.*

**Bulletin No. 100.* Percentage of Extraction of Bituminous Coal with Special Reference to Illinois Conditions, by C. M. Young. 1917.

**Bulletin No. 101.* Comparative Tests of Six Sizes of Illinois Coal on a Mikado Locomotive, by E. C. Schmidt, J. M. Snodgrass, and O. S. Beyer, Jr. 1917. *Fifty cents.*

**Bulletin No. 102.* A Study of the Heat Transmission of Building Materials, by A. C. Willard and L. C. Lichty. 1917. *Twenty-five cents.*

**Bulletin No. 103.* An Investigation of Twist Drills, by B. Benedict and W. P. Lukens. 1917. *Sixty cents.*

**Bulletin No. 104.* Tests to Determine the Rigidity of Riveted Joints of Steel Structures, by W. M. Wilson and H. F. Moore. 1917. *Twenty-five cents.*

Circular No. 6. The Storage of Bituminous Coal, by H. H. Stoek. 1918. *Forty cents.*

Circular No. 7. Fuel Economy in the Operation of Hand Fired Power Plants. 1918. *Twenty cents.*

**Bulletin No. 105.* Hydraulic Experiments with Valves, Orifices, Hose, Nozzles, and Orifice Buckets, by Arthur N. Talbot, Fred B Seely, Virgil R. Fleming, and Melvin L. Enger. 1918. *Thirty-five cents.*

**Bulletin No. 106.* Test of a Flat Slab Floor of the Western Newspaper Union Building, by Arthur N. Talbot and Harrison F. Gonnerman. 1918. *Twenty cents.*

Circular No. 8. The Economical Use of Coal in Railway Locomotives. 1918. *Twenty cents.*

**Bulletin No. 107.* Analysis and Tests of Rigidly Connected Reinforced Concrete Frames, by Mikishi Abe. 1918. *Fifty cents.*

**Bulletin No. 108.* Analysis of Statically Indeterminate Structures by the Slope Deflection Method, by W. M. Wilson, F. E. Richart, and Camillo Weiss. 1918. *One dollar.*

**Bulletin No. 109.* The Pipe Orifice as a Means of Measuring Flow of Water through a Pipe, by R. E. Davis and H. H. Jordan, 1918. *Twenty-five cents.*

**Bulletin No. 110.* Passenger Train Resistance, by E. C. Schmidt and H. H. Dunn. 1918. *Twenty cents.*

---

*A limited number of copies of bulletins starred are available for free distribution.

**Bulletin No. 111.* A Study of the Forms in which Sulphur Occurs in Coal, by A. R. Powell with S. W. Parr. 1919. *Thirty cents.*

**Bulletin No. 112.* Report of Progress in Warm-Air Furnace Research, by A. C. Willard. 1919. *Thirty-five cents.*

**Bulletin No. 113.* Panel System of Coal Mining. A Graphical Study of Percentage of Extraction, by C. M. Young. 1919.

**Bulletin No. 114.* Corona Discharge, by Earle H. Warner with Jakob Kunz. 1919. *Seventy-five cents.*

**Bulletin No. 115.* The Relation between the Elastic Strengths of Steel in Tension, Compression, and Shear, by F. B Seely and W. J. Putnam. 1920. *Twenty cents.*

**Bulletin No. 116.* Bituminous Coal Storage Practice, by H. H. Stoek, C. W. Hippard, and W. D. Langtry. 1920.

**Bulletin No. 117.* Emissivity of Heat from Various Surfaces, by V. S. Day. 1920. *Twenty cents.*

---

*A limited number of copies of bulletins starred are available for free distribution.

THE UNIVERSITY OF ILLINOIS

THE STATE UNIVERSITY

Urbana

EDMUND J. JAMES, Ph. D., LL. D., President

THE UNIVERSITY INCLUDES THE FOLLOWING DEPARTMENTS:

The Graduate School

The College of Liberal Arts and Sciences (Ancient and Modern Languages and Literatures; History, Economics, Political Science, Sociology; Philosophy, Psychology, Education; Mathematics; Astronomy; Geology; Physics; Chemistry, Botany, Zoology, Entomology; Physiology; Art and Design)

The College of Commerce and Business Administration (General Business, Banking, Insurance, Accountancy, Railway Administration, Foreign Commerce; Courses for Commercial Teachers and Commercial and Civic Secretaries)

The College of Engineering (Architecture; Architectural, Ceramic, Civil, Electrical, Mechanical, Mining, Municipal and Sanitary, and Railway Engineering; General Engineering Physics)

The College of Agriculture (Agronomy; Animal Husbandry; Dairy Husbandry; Horticulture and Landscape Gardening; Agricultural Extension; Teachers' Course; Home Economics)

The College of Law (three-year and four-year curriculums based on two years and one year of college work respectively)

The School of Education

The Curriculum in Journalism

The Curriculums in Chemistry and Chemical Engineering

The School of Railway Engineering and Administration

The School of Music (four-year curriculum)

The Library School (two-year curriculum for college graduates)

The College of Medicine (in Chicago)

The College of Dentistry (in Chicago)

The School of Pharmacy (in Chicago; Ph. G. and Ph. C. curriculums)

The Summer Session (eight weeks)

Experiment Stations and Scientific Bureaus; U. S. Agricultural Experiment Station; Engineering Experiment Station; State Laboratory of Natural History; State Entomologist's Office; Biological Experiment Station on Illinois River; State Water Survey; State Geological Survey; U. S. Bureau of Mines Experiment Station.

The library collections contain (October 1, 1919) 443,614 volumes and 53,037 pamphlets.

For catalogs and information address

THE REGISTRAR

URBANA, ILLINOIS

CALIF. HALL